The Retina as a Neuromimetic Model to Extract Data in Noisy Images: Application to Detection of Microcalcification Clusters in Mammography.

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Abstract
The nervous system is a powerful information processing machine, especially for vision. Neuromimetic methods try to extract some of the most powerful strategies of the neural system to apply them to help to solve delicate engineering problems. We developed such a method to extract images hidden into noisy background. This method mimics one characteristic of the retina which is a sensor that automatically adapts to the image characteristics and realizes outlines extraction and adaptative filtering, based on its network properties. We applied this method to detect automatically the clusters of microcalcifications in mammographies. Results were tested using the standardized data set DDSM, designed to test the automatic detection methods. We show that our "retina" can extract most of the microcalcifications that can be grouped together into clusters..

Keywords: image processing, neuromimetic method, retina, breast cancer, mammography.

1. Introduction

The nervous system can be viewed as a model of information processing machine. Namely, the visual system is probably one of the most powerful systems of information processing allowing to cope with dynamically and noisy incoming informations. The first stage of the visual system is the sensor itself, the retina. The retina is far from being a simple device transforming the light energy into electrical signal able to reach the visual cortex to be processed. A complex information processing is performed at the retina level, thanks to several types of neurons arranged in a complex network collaborating together to perform image enhancement, contour extraction, noise elimination local adaptation to luminosity, detection of moving targets, etc.

Since the end of the years 70, our team is interested by the information processing operated by the nervous structures. In this framework we worked on the modelling of the mammal retina to study the visual information processing by the retinal network[6,7]. We were able to show its ability to extract the outlines and to adapt automatically to the ambient conditions and therefore to automatically maintain the network in the optimum conditions. Since the retina realizes sequentially low pass and high pass filtering of the images, the retina is a sensor that automatically adapts to the image characteristics to treat and realizes the outlines extraction and adaptive filtering of the pictures, owing to its network property. We propose here a neuromimetic method inspired from the mammal retina preprocessing of visual information to localize automatically microcalcifications in mammographic images, by using a network of formal neurones whose connectivity is inspired from the mammal retina architecture.

We chose this application because the recognition of the early signs (microcalcifications) in mammographies remains one of the most difficult issues in the early detection of the cancers[2,3]. The earliest –then smallest– microcalcifications are difficult to visually detect, because the background can be very irregular (noisy), and the microcalcification image density is not very different from the background. Moreover, at the world-wide level, the breast cancer remains the major cause of the women deaths between 40 and 60 years. In France, it is the most frequent of the women cancers[1]. The mammography is the choice examination for the early identification of the tumors in an asymptomatic population. As effective preventive policies on a large scale would need to process huge number of mammographies, it would be interesting to have an automated method in which no suspect picture could pass unnoticed[4]. Automatic detection methods were already proposed[5]. Currently, the computer techniques were disappointing and the operator eye still remains the better judge. It could therefore be interesting to try a method based on neuromimetic technics mimicking the human eye to attempt to improve such a detection.

2. Material and methods

Definitions

In this paper, "event" is a pixel for which one the level value of grey surpasses a given threshold, after the preprocessing realized by the detection systems. "4-related" objects are objects whose 4 sides connect similar objects. "Spot" is a grouping of 4-

related events, or an event remained isolated after the determination of the spots. "Alert" is a spot surviving the selection process described below. The "***r***-cluster center" is the pixel at the center of a disc of radius ***r*** (defined below) having a not null intersection with at least ***n*** alerts (***n*** is a parameter of the detection algorithm, see below). We define a "cluster" as a 4-related body of the union of the dilated (by a circle of radius ***r***) centers of clusters.

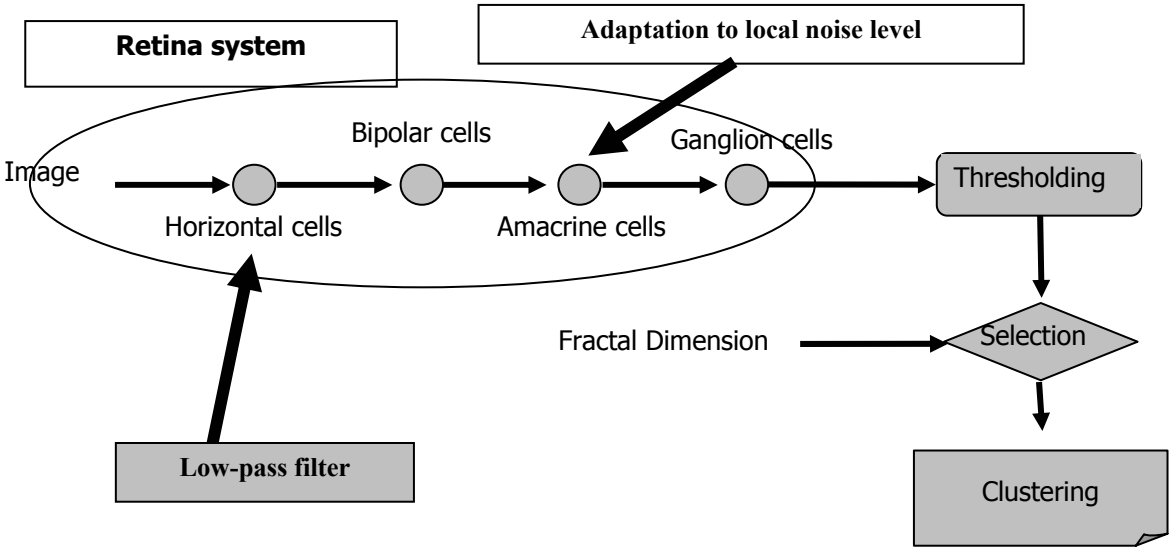

Figure 1: *The different steps from the image (the mammography) to the clustering of microcalcifications. The neuromimetic steps are inside the oval labelled "Retina system".l.*

Detection of microcalcifications

The retina model : The microcalcifications detector is composed of five types of cells that form two distinct pathways, inspired from the ON pathway of the mammal retina. The first pathway corresponds to the direct pathway: each pixel from the original image is the input to the "bipolar cell", itself directly connected to the "ganglion cell", the output of the retina. The second pathway corresponds to the indirect pathway, with the "horizontal" and "amacrines" cells. Each horizontal cell receives from several (for example 625 (25x25)) neighbour pixels and inhibits the corresponding bipolar cell (this one here realizes therefore the subtraction between the value of the pixel and the average of the 625 pixels being close to, and adapts therefore to the local average luminosity). Every amacrine cell receives the absolute value of the output of the numerous (for example 32761 (181x181)) bipolar units being close to and inhibits the corresponding ganglion cell (this one realizes therefore an adaptation to the level of local average noise). The horizontal cells calculate the local average of the luminosity; it is a matter of a fuzzy low pass filter. The bipolar cells compute the difference between the value sent back by the horizontal cells and the real luminosity. The whole set generates a high pass filter.

The amacrine and ganglion cells realize the adaptation to the local level of the noise as the horizontal cells calculate the local average of the luminosity. They compute the average of the absolute values of the output of the bipolar cells (on a radius a lot bigger than one of the horizontal cells, but using the same principle). The ganglion cells divide the output of the bipolar cells by the one of the amacrines cells. They allow the system to adapt itself at the local level of noise. The output of the ganglion cells is thresholded, and allows to select the "events" on which subsequent processing will be done, in order to determine the "spots", the "alerts" and finally the "clusters", that are in fact the important elements for the diagnosis. Figure 1 schematizes the different steps from the image (the mammography) to the clustering of microcalcifications, explained below.

Event detection: The grey level threshold above which a pixel is considered being an event was determined by a preliminary parametric analysis (see infra). Events were grouped together according to specified rules, allowing obtaining spots. At this point, some isolated events without significance, (for example due to noise) can still persist. In order to eliminate such events, an opening with an element more or less large is realized. This operation is realized after the thresholding and realizes again a low pass filter. Then, 4-related events are grouped in "spots", some of them become "alerts" if they are preserved after the selection

operations aiming to conclude that a spot is or no a microcalcification. This selection is based on the computation of the fractal dimension of the local image and on the diameter of the spots. By their nature little noisy and strongly contrasted, non biological artefacts as the edges and eventually the labels or the instrumentations (clips, needles) could cause false alarms and when these are close together, they can falsely appear as clusters. Fractal dimension are computed for an 11×11 pixels area from the surrounding 33×33 pixels area to eliminate all spots with a fractal dimension lower than 2, since we determined from our data that they represent non biological structures. Elimination of the spots by their average diameter is based on the fact that the diameter of a microcalcification ranges between 100 µm to 1 mm[10]. Consequently, only the spots with an average diameter between 2.3 pixels (100 µm) and 23 pixels (1 mm) are kept. This preselection reduces the quantity of information, improves their quality and reduce the computation time.

Determination of clusters

Clusters are groupings of microcalcifications, and are predictor of breast cancer. Isolated microcalcifications have no signification. We consider that there is a significant grouping around a point if the number of alerts to a distance less than a given radius (***r***) of this point is greater than a given number ***n*** (the two parameters, ***n*** and ***r***, can vary). All the alerts are expanded by a circle of radius ***r*** in order to show the other alarms participating in the detection of the "candidate cluster". The surface delimited by the set of circles of radius ***r*** containing at least ***n*** alerts is considered as a cluster (Fig 2-top panel). This surface is compared to the zone declared as being a cluster by the DDSM. One considers that there has corroborating detection between the DDSM and our system when these two zones have a not null intersection (Fig 2-bottom panel).

Test material

The mammograhic images that we used to test the system are from the DDSM (Digital Database for Screening Mammography) (http://marathon.csee.usf.edu/Mammography/Databaseb.html), a database created as a collaborative effort implying the Massachussets General Hospital, the University of South Florida, and the National Sandia Laboratories[8]. It was developed to allow the comparison of the performances of the various methods developed by the researchers working on this problem. This database is freely downloadble on Internet (ftp://figment.csee.usf.edu/pub/DDSM/). Each mammography was digitized with a 600 dpi scanner and is a rectangular picture of 1411 to 5311 pixels wide and 3376 to 6871 pixels height. Each pixel is 12 bit depth (4096 levels of grey, from 0, the

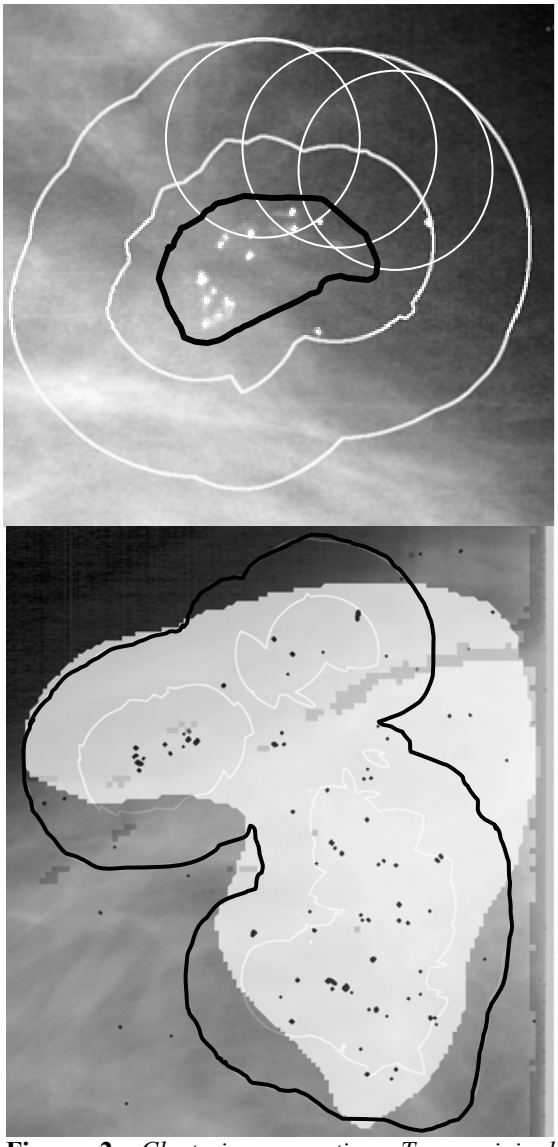

Figure 2: *Clustering operation. Top: original mammography (case A_1250 RMLO) with the result of the microcalcifications detection. White losanges are the detected microcalcifications, or part of them. The circles are those containing at least n (here 2) microcalcifications. The inner closed curve is the geometrical locus of these circles center, and the outer closed curve delimits the area covered by these circles. To clarify the figure, the circle radius is here very large. The black line indicates the contour of the DDSM cluster, completely included into the automatically detected zone. Bottom: (case A_1698 LCC). With normal size circles, and with a complicated shape of the microcalcification zone, the clustering algorithm detects correctly the DDSM area. Black line: detected cluster. Light grey area: DDSM cluster. Black dots detected microcalcifications. Dark grey dots: zones eliminated by their fractal dimension.*

darkest to 4096, the clearest). A pixel corresponds to a square of 43.5 µm aside on the mammography. The DDSM labels only clusters of micocalcifications, no individual ones. A "DDSM-cluster" is therefore the region delimited by the DDSM as containing one or more groups of microcalcifications. Our case definition, in this study, is a cancer containing one cluster of visible unilateral microcalcifications on the cranio-caudal view. Our initial sample study includes 203 cases with 4 mammographies by case (left and right breasts, cranio-caudal and mediolateral-oblique incidences), i.e. 812 mammographies, 406 with microcalcifications and 406 of undamaged breasts. The set of the 812 mammographies was treated and analyzed. The statistical study of the whole data (not shown) demonstrated that results coming from the two views of a same breast (cranio-caudal and mediolateral-oblique) were highly correlated. Therefore, the final studies were realized on 406 mammographies using cranio-caudal view (203 with microcalcifications and 203 undamaged ones).

Evaluation of results

To evaluate the performances of the detection method of clusters of microcalcifications in the mammographies, sensitivity and specificity were calculated. We used as gold standard the cluster definition of the DDSM: a true positive (TP) is a mammography with lesion in which at least one cluster is detected. One considers as false positive (FP) a healthy mammography in which at least one cluster was detected and as true negative (TN) a healthy mammography in which no cluster was detected.

The sensibility is the percentage of TP in comparison with the number of mammographies with cancer, and the specificity is the percentage of TN in comparison with the number of healthy mammographies.

Technicals

Programs were written in C language on PCs running Linux. Breast tissue detouring was performed manually using The GIMP.

3. Results

Figure 3 shows a mammography, on which the DDSM cluster was correctly detected by the neuromimetic method. Moreover, it displays also that some parts are correctly eliminated by computing their fractal dimension. Also a false detection can be seen at the top of the image. The "retina" wipes out the noisy background and make the microcalcifications visible, thanks to the horizontal cells, that make contour extraction, and to the amacrine cells that perform a local adaptation to the local luminosity.

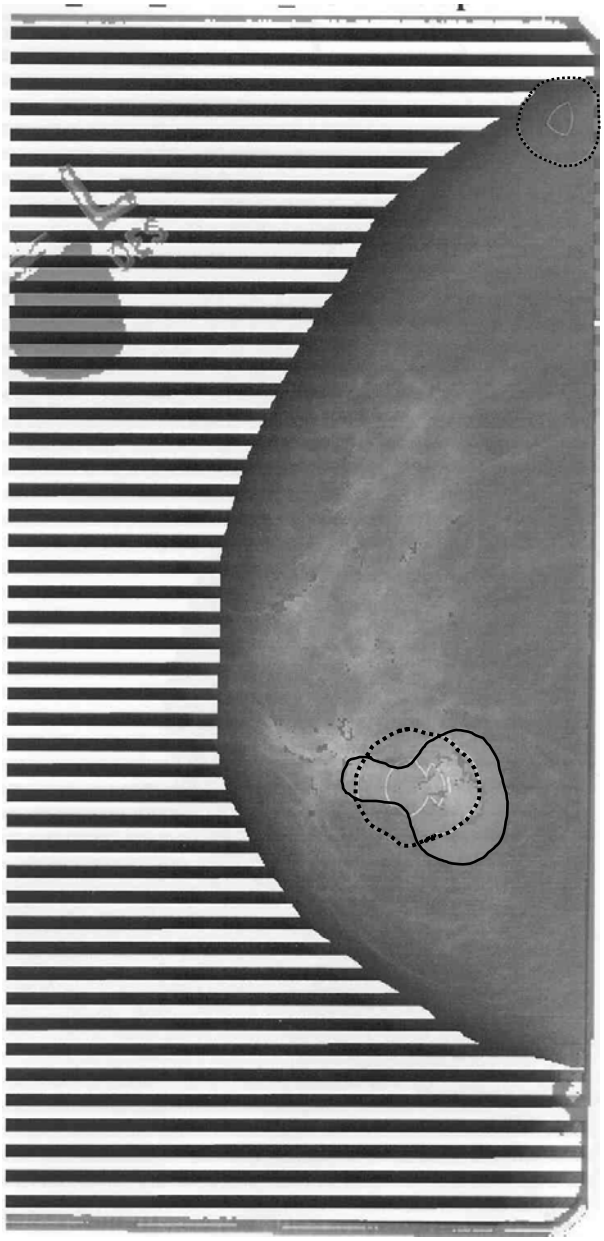

Figure 3: *The final step of the automatic processing of a mammography (case A_1243 of DDSM, left breast, cranio-caudal incidence) by the retina followed by the clustering algorithm. The closed curve indicates the localization of a cluster of microcalcifications as stated by DDSM. Automatic detection of clusters is represented by the dotted closed curves. Microcalcifications are small grey dots that are delimited inside dotted lines. Areas eliminated by the fractal dimensions are dark gery dots outside dotted lines. Detection algorithm is performed in the breast, out of the stripped area (manually delimited). Note that the DDSM cluster was correctly detected while not exactly superimposed. However one other zone (top right) was a false positive.*

This detection system is based on several parameters (thresholds, number ***n***, radius ***r***, spread of horizontal or amacrine influence) which can be adequately tuned. To guide this tuning, sensibility and specificity can be systematically assessed. A parametric study was performed to determine the best parameter choice. The actual study was made using, for all 812 mammographies the same set of parameters. It appears that in these conditions, if the sensitivity can be good, but with a low specificity. We work now to increase the system sensitivity by taking into account the fact that both breasts of a given patient have generally the same density, with a similar type of background. This can allow to automatically adapting the whole set of initial parameters to each patient, being considered that bilateral cancer is an exceptional situation.

4. Conclusion

Nature developed efficient information processing strategies. We tried to extract the minimal features to treat the difficult problem of the extraction of very small images hidden in a noisy background. Alaylioglu and Aghdasi[11,12] noticed that all the detection systems have the same structures basis. They always begin by a high pass filtering followed by an adaptive thresholding to the local noise and finishes by a clusterization. Optional steps can be added such as a selection of the alarms after the thresholding, a selection of the clusters or a low pass filter before or after the high pass filter to generate a passe band filter that is less sensitive to the noise of digitizing. The method presented here does not breach to these rules, but exploits the neuromimetic approach to perform all this work in fewer steps. Nevertheless, this problem is difficult to solve even by the experts that are not always concordant in their conclusions, while they use their eyes helped by their knowledge. Here, we mimick only the eye, and a very small part of the knowledge (the fact that microcalcifications must be grouped into clusters to be of interest). Nevertheless, the system detects correctly the individual microcalcifications, even with a set of parameters which, at the present stage, is the same for all images, while mammographies can have dramatically different background, trabeculation or density. We hope to improve this results by taking into account the fact that both breasts of a given patient can be considered as paired images and thus adapt automatically the whole set of initial parameters.

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